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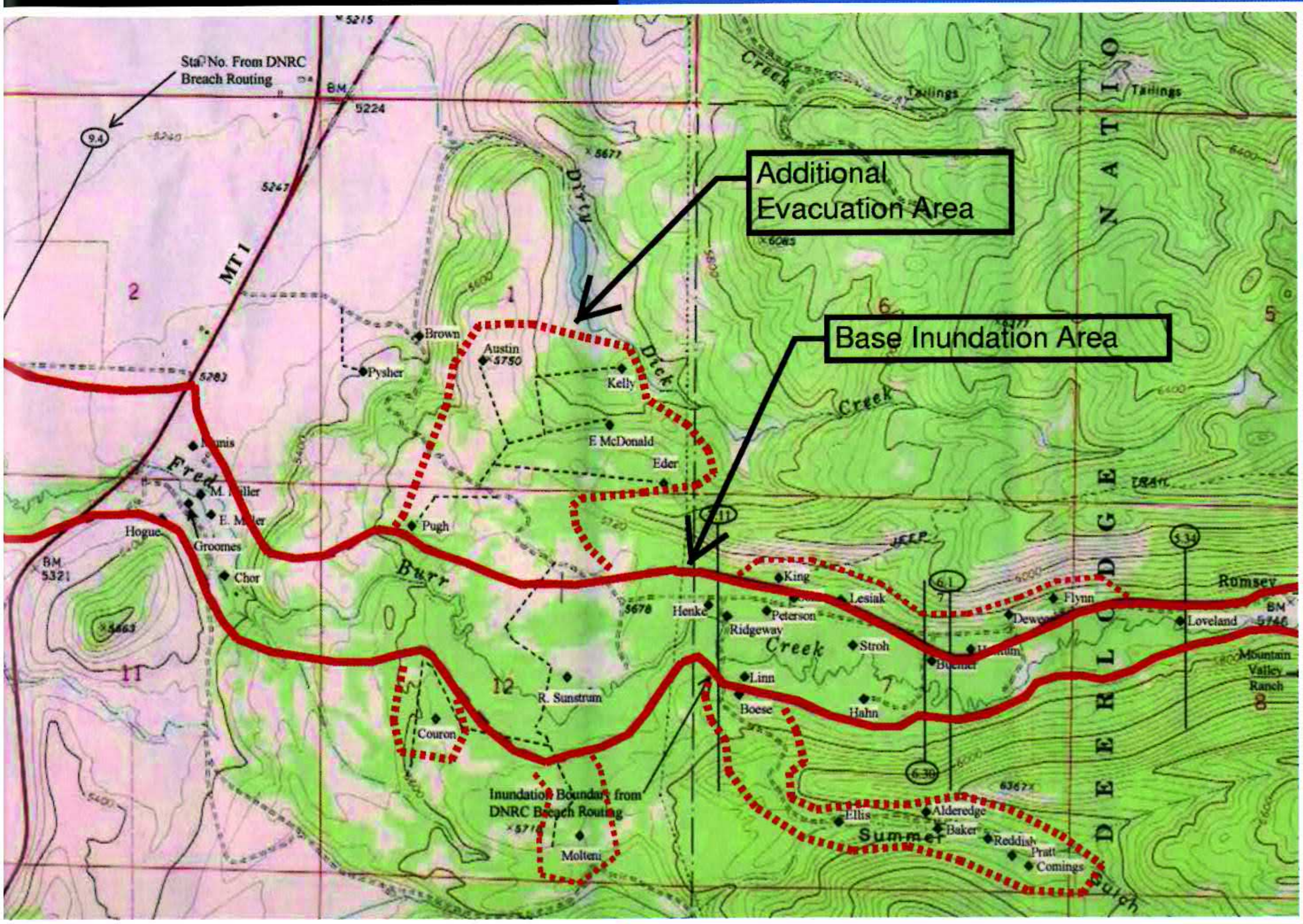

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THE DELAWARE DAM INVENTORY 2008:
A COMPREHENSIVE APPROACH TO FINDING REGULATED DAMS IN THE FIRST STATE

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ABSTRACT

In 2004 the Delaware legislature passed a dam safety law, authorizing the Department of Natural Resources and Environmental Control (DNREC) to implement a Dam Safety Program for the state. Delaware was one of the last states in the country to start a dam safety program, and the State had very little information about the location and nature of the dams that would be regulated. DNREC realized that a statewide dam inventory update was needed, not only to locate dams, but to also determine which dams would be regulated. The Delaware dam safety law limits regulatory authority to publicly owned, high and significant hazard potential dams.

To establish a modern inventory of Delaware dams meeting the law's criteria, DNREC retained and worked with URS Corporation to determine the location of all potentially regulated dams within the state, and to conduct a hazard potential and risk assessment for each identified dam. Dam ownership, dam characteristics and reservoir size were used to prioritize the field investigation of all potentially regulated dams. Because the Delaware law does not regulate low hazard potential dams, it was necessary to conduct a preliminary hazard potential assessment to determine whether a dam would be regulated or not. Approximate methods were used for this assessment (based on downstream impacts identified during field investigations), because funding was not available to perform detailed studies for each dam. A preliminary risk assessment was also conducted based on dam and reservoir observations. The end goal of the risk assessment was to prioritize the Delaware statewide dam inventory into high, medium and low risk categories for the purpose of future resource allocation. Risk assessment tools and strategies were designed to be flexible in nature, so that more accurate data can be easily incorporated into the process. Accurate data will be obtained through future detailed hydraulic modeling and comprehensive field inspection of each dam.

PAST DAM INVENTORIES IN DELAWARE

The first comprehensive effort to inventory dams in Delaware was completed in April 1974 by DNREC and the University of Delaware (UD), working with the US Army Corps of Engineers (USACE) as part of the National Program of Inspection of Non-Federal Dams. The goal of this inventory was to locate dams that met the criteria for inspection under PL 92-367, enacted by Congress in 1972. This study found 57 dams throughout the state that met the size criteria for inspection (dam height of 25 feet (7.6m) or greater, or impoundment of 50 acre-feet or greater) as shown in Table 1.

Table 1 – Distribution of Large Dams Identified in 1974 Inventory

New Castle County	14 dams
Kent County	18 dams
Sussex County	25 dams

In addition to the 57 dams that met the USACE inspection criteria, the 1974 inventory located 58 smaller dams distributed as summarized in Table 2.

Table 2 – Distribution of Small Dams Identified in 1974 Inventory

New Castle County	46 dams
Kent County	3 dams
Sussex County	9 dams

From 1978 to 1981, USACE (with limited assistance from DNREC) developed the initial Delaware dataset for the National Inventory of Dams (NID) program, using the 1974 inventory as a starting point. Based on these efforts, a total of 96 Delaware dams were recorded in the 1981 NID. These included 17 federally owned dams used to impound dredge spoil material from the Chesapeake & Delaware Canal and the Delaware River, and eight dams that were part of various municipal wastewater treatment lagoons. None of these dams had been included in the 1974 inventory.

Since 1981, NID listing criteria have changed, resulting in removal of many of the smaller dams that were originally included. Prior to the 2008 inventory update, Delaware's NID dataset consisted of information for 61 dams, as shown in Table 3.

Table 3 – Pre-2008 Delaware NID Dams

New Castle County	19 dams
Kent County	15 dams
Sussex County	27 dams
High Hazard	9 dams
Significant Hazard	27 dams
Low Hazard	25 dams

While the number of Delaware dams on the NID has changed since 1981, the information about those dams - including such basic data as the name of the dam owner - dates to 1981 and in some cases to 1974.

During 1999 – 2003, the University of Delaware Water Resources Agency (UDWRA) prepared a report for DNREC, the Delaware Emergency Management Agency (DEMA) and the Federal Emergency Management Agency (FEMA) outlining the steps necessary for development of a state Dam Safety Program. As part of this study, UDWRA performed a limited-detail, GIS-based update of the state's dam inventory. This update resulted in a database of 176 dams, summarized in Table 4.

Table 4 – Summary of 2003 UDWRA Inventory Update

High Hazard	13 dams
Significant Hazard	28 dams
Low Hazard	53 dams
Hazard classification not reported	82 dams
Publicly owned	72 dams
Privately owned	49 dams
Owner not reported	55 dams

Of these 176 dams, 111 are not included on the NID, and 29 of these 111 dams were not included on any previous state inventory.

DEVELOPMENT OF THE DELAWARE DAM SAFETY PROGRAM

Proposed dam safety legislation for Delaware was drafted in 1979, based on the Model Law of the United States Committee on Large Dams (USCOLD). The legislation was introduced in the legislature in 1980 and 1981, but was never enacted. The issue of establishing legislation and a Dam Safety Program for the state was not addressed again until 1998 when the state requested participation in the National Dam Safety Program directed by FEMA. The availability of FEMA grant funding allowed UDWRA to undertake their study in 1999, which outlined the framework of a Dam Safety Program for the state and included draft legislation, based on FEMA's Model State Dam Safety Program.

In 2000, while the UDWRA study was underway, DNREC formed a Dam Safety Guidance Committee consisting of state and municipal officials, state legislators, representatives from ASDSO, FEMA and DEMA, and several private dam owners. New legislation based on FEMA's Model State Law was drafted and introduced in the legislature in June 2000. Private dam owners raised concerns that were primarily focused on the cost to dam owners if a Dam Safety Program were implemented, and those concerns were significant enough to keep the legislation from moving forward.

Finally in 2004 after much negotiation - and several critical editorials in a local newspaper - a compromise dam safety law was passed by the legislature and signed by the Governor. The law required regulation of publicly-owned, high and significant hazard potential dams, and authorized DNREC to establish a Dam Safety Program and promulgate regulations. The law was not effective until funding for the program could be provided in the state budget, which occurred in 2005.

Once the Delaware Dam Safety Program was established and funded in 2005, the first two priorities were writing regulations and establishing which dams in the state met the law's criteria for regulation. The Delaware Dam Safety Regulations are currently in final draft form and DNREC expects that they will be promulgated in 2009.

Because Delaware had no Dam Safety Program since the inception of the NID, the state's NID data had never been routinely updated, and the few periodic updates that occurred over the past 25 years had not been comprehensive. URS Corporation was retained by DNREC in June 2006 to undertake a comprehensive review of all of the past state dam inventories and find dams in the state that were not on previous inventories, with the ultimate goal of developing the list of regulated dams to be used by the Delaware Dam Safety Program.

DELAWARE DAM INVENTORY 2008 - INITIAL PROCESS

The method of analysis for identifying and prioritizing potential dams consisted of first collecting existing information from previous inventory lists as well as other data that could indicate the presence of a dam. The method for searching and locating potential dams and determining probable ownership (public or private) consisted of the following nine steps:

> (1) The 1981 and 1999 NID dam datasets, the GNIS dam dataset, the UDWRA dataset, and the 1974 State Inventory were plotted by their given latitude and longitudes (when available) and compared to 2002 Color Infrared Orthophotos, 2006 Color NAIP imagery, and the 2002 Landcover data. Dam point features were moved to coincide with the dam structure shown in the orthophoto.

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FIGURE 1 - Location of 323 Dams Identified in Inventory

(2) When it was not clear which dam feature a dataset was referring to, web-searches and parcel ownership searches were conducted for additional location information. When only the name of the dam was available, the complete GNIS dataset of all named features in Delaware, and web-searches were used to aid in the location identification.

(3) Duplicate entries were eliminated with preference given to the NID datasets.

(4) Additional dams were placed based on orthophoto/hydrological features by scanning up- and downstream tributaries.

(5) Additional dams and dam or reservoir features were identified during a line-by-line grid search scan of all USGS topographic maps. The features were then placed accurately on the orthophoto base.

(6) All results were compiled, and a final scan of hydrological features and dams was made to verify that all likely dams were identified.

(7) Each potential dam was then compared to ownership property information, and if any public ownership was touching or close to the dam, the dam was assumed to be on the public property. This conservative approach was taken due to the imperfect spatial accuracy of parcel layers. A separate, detailed dam-ownership study will be conducted by the state to confirm all publically owned dams of interest.

(8) Based on NID ownership information, all federally owned dams were separated out from the public dam dataset. If there was a conflict between NID ownership data and parcel ownership data, then the conservative approach was taken and the dam was left in the public data set. Both parcel and NID ownership information remain as attributes in the dam database, to be resolved as part of the detailed dam-ownership study (see above).

(9) Dams were linked to the nearest water body, and their heights estimated based on the NID height data, or topographic contour data if NID height data wasn't present. This information was used to calculate the approximate storage area in acre-feet. Due to the relatively low topographical relief in the State, only five dams have calculated heights greater than or equal to 25 feet (7.6m) in height. Therefore impounding capacity will be of greater importance than dam height when determining dam status.

The preliminary dam identification efforts resulted in 323 unique dams located throughout the State (see Figure 1). After locating all dams and categorizing them according to probable ownership, the dams were further prioritized as discussed below.

CONDUCTING FIELD REVIEWS, INFORMATION GATHERED

There were 14 different possible combinations (numbered 1 through 14) of existing data based on the prioritizing criteria used. These 14 combinations were ranked in order of priority based on the dam's potential for being regulated. They were then aggregated together by "Class" (designated A through F) based on similar values (i.e. dams from the 1999 NID with a high hazard class and dams from the 1981 NID with a high hazard class are deemed to have equal importance, and therefore share the same class). The "A" class represents the highest priority, and "F" class the lowest.

Due to scope and budget constraints for this phase of the project, it was decided to visit the dams categorized as publicly owned and classified as A, B, and C. The A, B, and C dams included 91 of the highest priority dams and included several recently constructed structures identified using information supplied by DNREC and 2006 NAIP imagery.

A field data form was prepared and used to gather the pertinent information for each structure, and included information such as dam height, channel elevation, top of bank, toe of slope, dam type, and general physical condition. Site photography was used to document the condition of the dam, spillway, pipes, culverts, banks, and training walls. A field sketch was made for each dam to show where photos and measurements were taken. It is important to note that the purpose of the field visits was to collect data for populating the database and they do not constitute a dam safety inspection. No structural or geotechnical inspections or tests were performed for this study.

BUILDING THE DATABASE

The dam database was developed to track and manage the spatial location and attributes of all 323 potential dams in the new State inventory. The database was originally based on the NID database structure. Key NID attributes that pertained to hazard and risk assessment were copied into the dam inventory database. The database was then expanded to include information collected during the field visits and data derived through hydrologic, terrain, and watershed modeling. Finally, impact analysis, hazard classification, and risk assessment results and comments were added to the table to provide a comprehensive description and overview of the current body of knowledge for each dam. The database was designed to be flexible in nature and to allow the addition of new attributes or modification of existing attributes and spatial locations. Dams can also be added or deleted as structures are constructed or removed.

PRELIMINARY HAZARD CLASSIFICATION DETERMINATION

Method

For the purpose of determining the regulatory status of the dam, a dam must have a hazard classification of either high or significant hazard potential according to the state's dam safety legislation. For the purposes of this study, a preliminary dam hazard classification was assigned based on:

- Dam height
- Approximate downstream inundation area based on topography and dam height, assuming a brim-full, sunny-day dam break scenario
- Structures and infrastructure at risk within the inundation area

Dam Height

The dam height was estimated based on field surveyed information. The dam height was generally computed as the vertical distance between the dam crest and the lowest point in the downstream channel at the dam's downstream toe, if available. If the channel point was not available, then the downstream bottom-of-bank points were used as a close approximation. Typically the highest point associated with a dam (dam crest) was used as a factor when determining the maximum height that water may reach in the event of a brim-full sunny day dam break. The brim-full condition is conservatively assumed to represent a potentially blocked spillway or outlet works that would allow the pool level to rise to the top of the dam.

Approximate Downstream Inundation Area

The sunny-day, brim-full dam failure inundation area was estimated in accordance with the Guidelines on Risk Assessment, published in 2003 by the Australian National Committee on Large Dams Incorporated. These guidelines state that a basic downstream inundation area can be calculated by determining the flood peak height and then routing it downstream. For this study, it was assumed that the flood peak height could be approximated by multiplying the total dam height by a factor of 75 percent. This dam height factor was based on numerical modeling of two dams and a review of several previous inundation studies for dams with similar landscape conditions. This level of analysis is a conservative estimate, as flow dispersion and attenuation is not taken into account as the flood wave moves downstream. The flood wave was routed for 1 to 3 miles downstream, or until the channel opened up significantly, or intersected a larger channel with a larger, well-established floodplain.

Structure/Infrastructure at Risk

Buildings within estimated inundation limits were identified as either residential or commercial based on building size and shape, and the presence of parking lots or commercial traffic. Schools and hospitals were identified using the USGS GNIS. Campgrounds were identified from the orthophotos and park data. Road and railroad information was acquired from the Environmental Systems Research Institute (ESRI) Streetmap 9.2 data set. Structures or infrastructure were considered at risk if they were located within the estimated inundation area, or at slight risk if on the boundary of the estimated inundation area. The type of buildings and infrastructure at risk was recorded as an attribute of the dam, and buildings or structures at risk were flagged using a point shapefile. This shapefile can be modified based on further detailed analysis.

Preliminary Hazard Classification

The state's dam safety legislation provides for three hazard potential classifications, which are defined as follows:

- "'High Hazard Potential Dam' shall mean any dam whose failure or mis-operation will cause probable loss of life."

FIGURE 2 - Location of 63 Potentially Regulated Dams in Delaware

- "'Significant Hazard Potential Dam' shall mean any dam whose failure or mis-operation will cause possible loss of human life, economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns."
- "'Low Hazard Potential Dam' shall mean any dam whose failure or mis-operation is unlikely to cause loss of human life but may cause minor economic and/or environmental losses."

In order to assign a preliminary hazard classification for the probable regulated dams, the following guidelines for evaluating impacts were used for assessment:

- High – A dam failure would typically affect multiple residential or commercial structures, and significant infrastructure such large roads or a railroad, urban areas, schools, or hospitals.
- Significant – A dam failure may result in a slight risk to one residential structure, or minor infrastructure such as small roads or pumping structures, or may have environmental consequences.
- Low – A dam failure would likely only affect agricultural or undeveloped land or a minor road if it is part of the dam structure.

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Results

Based on the above methodology and assumptions, the structures of interest were assigned a preliminary hazard classification and regulation status based on ownership and hazard classification. A summary of the number of dams and preliminary hazard classifications is provided in Table 5. Note that the number of structures of interest decreased from 91 to 86 as field observations revealed that several of the dams had been removed or were not actually dams, such as footpath bridges that did not impound water.

Table 5 – Hazard Classification Summary for Structures of Interest

Hazard Class	Structure	Regulated
High	71	58
Significant	6	5
Low	9	0
Total	86	63

Based on past experience in other states, there are a disproportionate number of high hazard dams compared to significant hazard dams. This may be due to the conservative methodology used for estimating the inundation areas and a lack of detailed knowledge with regard to the type and use of each structure that may be affected. Currently, there are 63 dams classified as potentially regulated structures located throughout the State based on the results of the dam ownership and hazard analysis (see Figure 2).

RISK ANALYSIS

A preliminary portfolio risk assessment was conducted with the objective to prioritize the dams within the Delaware dam inventory for the purpose of identifying dam safety needs and assisting in resource allocation. For the purposes of this study, the dams are classified into the three risk categories of A, B, or C, with A representing the highest relative risk and C the lowest. These categories are intended to be used primarily as a screening tool and are based on preliminary, top-level APD data as opposed to detailed modeling or comprehensive inspection data. Dam characteristics, field observations, downstream impacts, and reservoir estimates were used to help in the prioritization.

Method

The preliminary risk assessment prioritization was performed based on estimating the:

- Characteristics of the dam, spillway, reservoir, and drainage basin
- Loss of life potential (LLP) based on structures within the approximate inundation areas
- Field observations of the general condition of the dam and ancillary features and noted deficiencies

Estimated values describing these elements were input into the URS-developed "Dam Risk Prioritization Tool" (DRPT) to determine relative risk values for each dam of interest in the state inventory. This tool was developed for FEMA under Task Order 278, Contract # EMW-2000-CO-0247, in 2007. It functions by building a portfolio of all dams within an inventory, and assigning dam elements, downstream impacts, and failure modes to each dam. It then summarizes those risks, and assigns an overall relative risk value to each dam for purposes of comparison. The risk values are then ranked and categorized based on current information and statistics.

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Dam, Spillway, Reservoir, and Drainage Basin Characteristics

A number of basin characteristics had to be quantified to satisfy the input requirements of the DRPT. These included the basin area, basin slope, mean basin elevation, mean annual precipitation, and main stream length. Indirectly, several other basin characteristics had to be measured in order to derive the 10-year discharge flow as described by the regression equations in the 2006 USGS paper *Magnitude and Frequency of Floods on Nontidal Streams in Delaware* (SIR 2006-5146). These included the drainage area, forested land cover, and water-body storage in the northern Piedmont region, and the drainage area, basin slope, and soils of hydrologic soil type A in the central/southern Coastal Plain region.

Dam characteristics required by the DRPT included the hydraulic height and spillway capacity. These measurements were either available from the NID database, or derived based on the field measurements and the use of the Weir equation $Q = CLH^{(3/2)}$, with Q = discharge, C = Weir coefficient (estimated at 3.0 to be conservative), L = Weir length, and H = head at overtopping.

Reservoir characteristics required by the DRPT included the maximum storage volume, the maximum reservoir area, and the probability of the dam impounding water in any one year.

Loss of Life Potential (LLP)

The LLP was estimated based on the number of people at risk (PAR) and the relationship between the peak breach discharge and the 10-year discharge. The PAR was estimated by counting the number of structures within the inundation area, and assuming that each structure contained three people. It is recognized that structures such as multiple family units or commercial structures may have more than three people contained within them, while other such as industrial storage sheds may have fewer than three people within them; however, the determination of an accurate people count per structure is beyond the scope of this study. The estimate of three people per structure can be modified if or when further information on structure usage becomes available.

The peak breach discharge was estimated using the Froelich equation:

$$Qp = 40.1*((V)^{0.295})*((H)^{1.24})$$

where:

Qp = the peak outflow in cubic feet per second from the breached embankment dam

V = the reservoir storage volume in acre-feet at the time of failure

H = the height of the embankment in feet from the bottom of the final breach to the top of the embankment

The LLP is proportional to the PAR times the ratio of the peak breach discharge to the 10-year discharge. Therefore, as the peak breach discharge increases in relation to the 10-year discharge, or normal flood events, the greater the LLP of the PAR becomes. The calculated peak breach discharge value can also be easily overwritten by the user if alternate data becomes available, such as computed breach flows from dam-break analysis.

For low hazard dams, the PAR was estimated to be zero, and thus the LLP was also zero. However, that value made any noted dam deficiencies negligible, as there was zero risk associated with the dam. To work around that technical issue, a very small LLP was assigned to those dams with noted deficiencies (LLP = 0.01), so that their risk values increased to reflect any severe deficiencies noted. It could also be argued that an LLP of 0.01 may also reflect the presence of any transient populations at the time of the dam break (hikers, fishers, etc.).

Dam Condition and Deficiencies

Specific type and severity of dam deficiencies is an important input parameter for quantifying the annual probability of failure using the DRPT. Site visits were performed to document the existence and physical features of the dam and to make measurements of features, if practical.

The four major categories of dam deficiencies noted during the field investigations and included in the risk prioritization included: a) excessive or woody vegetation or trees on the dams, b) poor condition of the spillway and/or inadequate spillway capacity, c) the presence of seepage, and/or d) the presence of deteriorated conduits through the dam. The observations within these categories were ranked and assigned failure mode values in the DRPT.

Inventory Results

Based on the risk analysis, preliminary risk categories were assigned to the dam and selected bridge structures in the State inventory (see Table 6):

Table 6 – Preliminary Risk Categories for Structures of Interest

Risk Category	Structures
A	34
B	32
C	20
Total	**86**

Several of the highest-risk dams contain stop-logs restricting the flow through the spillway. If the stop-logs were removed, then the spillway capacity may be adequate for high-discharge flood events; however, the removal would also lower the reservoir level. It is recognized that the use of active systems requiring human intervention are generally not looked on with favor unless there are full-time staff, automated monitoring and notification systems, and a firm plan in place should the need to remove the stop-logs

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arise. If these systems and dedicated staff are in place, the dam risk values may be decreased accordingly.

DELAWARE DAM SAFETY PROGRAM IMPLEMENTATION

DNREC is using the results of the Delaware Dam Inventory 2008 report in many phases of program implementation. URS recommends that the hazard classification and risk assessment results be used primarily as a screening tool to prioritize field inspection and dam break/flood inundation modeling resources. Estimates used throughout the course of the inventory investigation were made as consistently as possible between dams for the sake of comparative modeling and analysis. Additional data or detailed analysis available as the Delaware Dam Safety Program grows will help to increase the accuracy of the downstream impacts and the risk value associated with each dam. Consistent evaluation and input of data into the risk assessment tool will be an on-going effort in order to preserve the comparative accuracy of the results.

Listed below are five specific URS recommendations for follow-on activities from the Delaware Dam Inventory 2008 report, and how DNREC is addressing each recommendation:

1. Confirm public ownership of each dam of interest to determine if the dam is eligible to be a regulated structure.

Upon promulgation of the state's Dam Safety Regulations, DNREC will notify each owner of a regulated dam that DNREC has determined that they own a dam meeting the criteria for regulation, and that they will be subject to the provisions of the law and regulations. Dam owners must respond within a limited time period to either confirm their ownership of the dam or dispute their ownership, in which case DNREC and the dam owner will investigate the ownership of that particular dam separately. Since most of the regulated dams are owned either by the Delaware Department of Transportation (DelDOT), DNREC, or jointly by DelDOT and DNREC, only a small number of dams may require ownership investigation.

Several dams in the inventory may be jointly owned by a public entity and a private individual, a situation not specifically addressed in the dam safety law. DNREC's legal interpretation of the law is that they have authority to regulate these dams because at least part of the dam is publicly owned. DNREC does not have the authority or the ability, however, to require that the private individual bear any costs associated with compliance. Access and maintenance agreements will have to be negotiated between the public and private owners to allow the public entity to access private property for maintenance, inspections, and operation of the dam.

2. Perform a numerical dam-break analysis on each dam of interest to more accurately determine peak breach discharge, the inundation area, and the number of structures at risk and perform a detailed, formal dam inspection of each dam of interest to determine all dam deficiencies and hydraulic parameters.

DNREC and DelDOT currently have dam safety evaluations on-going with consultants for six regulated dams owned either jointly or by the individual agencies. These evaluations were started prior to completion of the 2008 dam inventory based on past incidents at the dam and/or legislative inquiry and DNREC concurrence. In addition, DNREC currently has four consultants under contract and preparing Emergency Action Plans and Operation & Maintenance Manuals for a number of other state-owned dams that were selected from the Risk Category A dams in the inventory report. DNREC is working with the other regulated dam owners to help them develop a capital funding needs analysis for their portfolio of dams, based on the results of the risk analysis. These analyses will form the basis for future legislative capital funding requests for the various public entities for dam evaluations and improvements.

3. Perform a land use/land zoning analysis to determine the type and use of affected structures. This information can then be used to update the PAR and LLP values.

DNREC is working with the Office of State Planning to develop methodology to incorporate the Dam Inventory 2008 inundation graphics into the state's Preliminary Land Use Service (PLUS) process, which is a comprehensive, multi-agency regulatory review that applies to most significant development projects in the state. The intent is to make developers aware that proposed developments may be within a potential dam breach inundation area, and to track proposed development that could change a dam's hazard classification. Also, the Office of State Planning in 2008 conducted a statewide update of aerial photography, which included creation of a new land use/land cover GIS layer that was not available to URS prior to completion of their report. This 2008 data will be used to update the risk analysis PAR and LLP values.

4. Secure funding to examine the additional 85 dam structures on public property that were not part of the detailed study (Priority D, E, and F dams in Table 7) to determine whether or not they should be regulated structures.

Funding for this activity will be requested as part of future Dam Safety Program funding requests.

5. Update the NID database based on current study results.

This was done as part of Delaware's 2008 NID update, marking the first time since the original NID was established that significant new information about Delaware's dams was added to the national inventory, including information about two new dams that were constructed since 2000. The current Delaware NID statistics are shown in Table 7.

Table 7 – Current Delaware NID Dams (2008)

New Castle County	26 dams
Kent County	22 dams
Sussex County	38 dams
High Hazard	65 dams
Significant Hazard	8 dams
Low Hazard	13 dams

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